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**INVESTIGATION OF TRACE METALS RELATED TO PLACER MINING ON
FAIRBANKS AND PORCUPINE CREEKS**

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INTRODUCTION

Trace metal concentrations in streams associated with placer mining have been a topic of discussion and research in the Alaska interior for more than a decade. Recently, concerns have been expressed about the concentration of certain trace metals in placer mining streams that are not monitored by the Alaska Department of Environmental Conservation. The concern was generated by earlier studies which showed high trace metal concentrations in streams being placer mining. However, much of the data cited were from studies conducted five to ten years ago. In general, the metals are associated with suspended sediment and regulations and mining practices have changed since then, drastically reducing the amount of sediment released to the streams. Through the combined efforts of the Alaska Department of Natural Resources, Division of Water (ADOW) and the Department of Environmental Conservation (ADEC), a study was conducted to measure the concentrations of **five** trace metals potentially associated with placer mining above and below two operating placer mines. The five metals of concern are: arsenic, cadmium, copper, lead, and zinc.

The objective of the study is to compare the water quality criteria of the five trace metals to the collected data. The criteria of the **five** metals are both time (instantaneous, **24-hour** and four-day means) and hardness dependent. A sampling scheme was derived which would look at the various time intervals.

Since most metals are carried preferentially by suspended particles (Baudo et al., 1990), it was decided to study mines which had a direct discharge to the stream. This would represent a “worst-case” scenario and would indicate if further investigations were necessary.

STUDY LOCATIONS

The two sites chosen for the study were based on the following criteria:

- 1) The mine chosen should not have another active mine upstream. It would be **difficult** to determine the effects of one mine if another mine upstream increased the sediment (and possibly metals) in the stream.

- 2) The discharge of the stream should not exceed 50 cfs. Large stream discharge could dilute metal concentrations below the detection limit. The goal of this study was to look at **potential "worst-case"** metal concentrations.
- 3) The sites should be located in different mining districts to include the effects of different geological settings.
- 4) The sluice should be in operation during some portion of the sampling period.
- 5) The mine should meet the settleable solids standard (less than 0.2 **mL/L**). Prior to collecting samples for trace metal analyses, the settleable solids concentration was measured at each site to check compliance with this standard. Periodic checks throughout the sampling period confirmed that settleable solids concentration never exceeded a trace.

Based on the above criteria, the following sites were chosen (see Figure 1):

Mine #1

The first mine sampled (June 17-21, 1991) is located on Fairbanks Creek east of Cleary summit, 7.1 miles above Fish Creek, within section 27, **T.3N., R.2E.**, Fairbanks Meridian. The mine is a typical placer operation using bulldozers for stripping and pushing **paydirt**, an excavator, rubber tire loader, a trommel washplant, and eight inch sluice pumps. The mine processes approximately 700 cubic yards of material per day with 800 gallons of recycled process water per minute.

The sluice operated with 100 percent recycled process water. Process water from the sluicing and infiltration water from the mining cut are treated with simple settling using the first pond as a presettling pond, with subsequent ponds functioning as settling, polishing, and recycling ponds.

The recycle/settling pond system is built in mining cuts that remain behind as mining progresses up the valley. Each pond is different due to the fact that overburden from the next cut is deposited in the previous cut, and settling basins are fashioned from the available area after stripping is complete. Average dimensions are approximately 100 feet wide by 200 feet long by 30 feet deep. The operator reclaims the disturbed areas below the mine as mining progresses up the valley.

The mine is located in the upper reaches of the valley. The stream is low volume (less than one cfs above mining) and is bypassed around the cuts into **the** ponds. According to the operator, the entire streamflow is needed as makeup water into the ponds to keep up with the outgoing pond seepage. This results in an intermittent, variable discharge through the summer. During the five days of sampling the ponds produced a nearly constant discharge. However, numerous seeps in the valley between the sampling sites increased the flow by a factor of four.

Mine #2

The second mine sampled (August 5-9, 1991) is located on Porcupine Creek 5.4 miles above Bonanza Creek within section 4, **T.8N., R. 1 1E.,** Fairbanks Meridian. Access to the site is from mile 114 Steese Highway via Porcupine Creek Road. The mine is also a typical placer operation using bulldozers to remove overburden and push **paydirt**, a backhoe, a 40 foot sluice, a double-decked screen with two conveyers and a pump. The operation consists of a series of cuts approximately 200 feet by 700 feet with mining progressing upstream. The backhoe feeds the wash plant via a conveyor. The larger material is screened **from** the plant and diverted via another conveyor prior to sluicing. The mine processes approximately 900 cubic yards of material per day with 800 gallons of recycled process water per minute,

The sluice is operated with 100 percent recycled process water. Process water from sluicing and groundwater infiltration from the mine cut are treated with simple settling via a series of five ponds including a pre-settling pond and recycle pond. New ponds are constructed from the old mine cuts. Lower ponds are filled/reclaimed as the operation progresses up the valley.

Porcupine creek is completely diverted around the mine site. **Groundwater** seeping in from the upstream cut provides sluice water that is recycled from the second pond. Groundwater infiltration into the ponds is estimated at 200 to 300 gallons **per** minute. Two creeks supply additional water to Porcupine Creek between the above-mining and below-mining sites. Yankee Creek flows in from the south and an unnamed creek flows in from the north,

LOCATION OF SAMPLING SITES

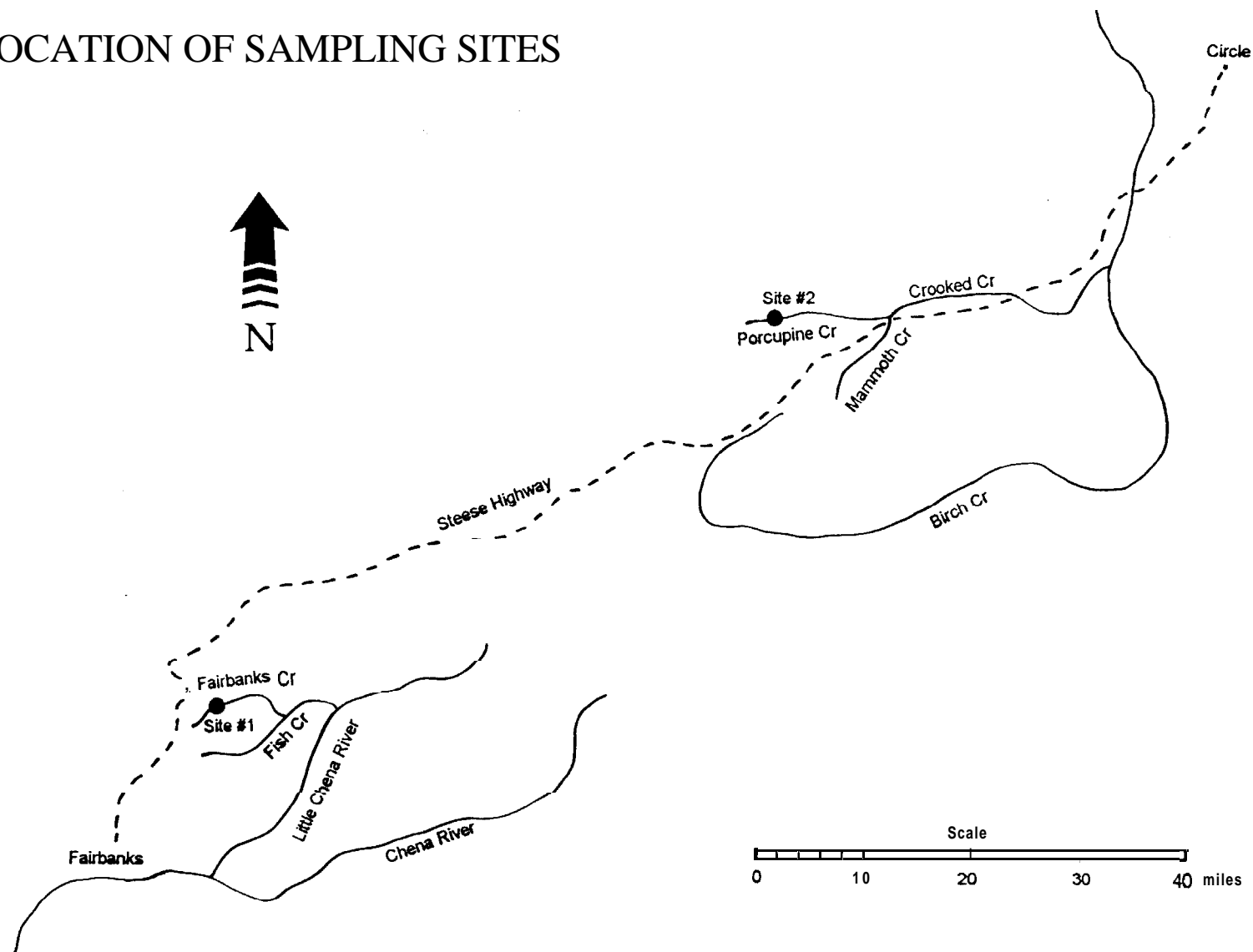


Figure 1. Location of sampling sites.

METHODS

Discharge

Stream velocities used in the discharge calculations were measured with a standard pygmy meter. Velocities were measured at six-tenths depth, with **sufficient** number of sections such that no one section contained over ten percent of the flow, Discharge was calculated using the standard midpoint method (USDI, 1981).

Water Quality

Samples for water-quality analyses were obtained using a hand-held depth-integrating sampler and a chum splitter (USDI, 1977). Composite samples collected from the churn splitter were processed according to each parameter in compliance with approved methods (USEPA, 1982). Filtered samples were processed with 0.45 μm membrane filters. Acidification was done with Ultrex-grade nitric acid.

Water temperature, dissolved oxygen and **pH** were measured in situ using portable meters. Conductivity and turbidity were measured on the composited sample using meters. Hardness was measured on the composited sample by titrating with EDTA.

Laboratory Analyses

Water-quality analyses were conducted at the Alaska Division of Water • Water Quality Laboratory at the University of Alaska Fairbanks campus. The laboratory is a participant in the **USEPA** Performance Evaluation program as well as the USGS Standard Reference Water Quality Assurance program. Analytical methods and detection limits are outlined in Table 1. For all parameters, calibrations were performed using NBS traceable standards where applicable. General data reduction procedures are described in Standard Methods (APHA, 1989).

Digestions for total metals and total recoverable metals were carried out using **USEPA** methods (EPA, 1983). The method for total recoverable metals is a mild digestion where the acidified sample is reduced once before returning it to its original volume. Samples for total metals are reduced and refluxed with

several additions of acid before returning the sample to its original volume, which results in a more thorough and complete digestion of the sample.

Table 1. Analytical *methods* and detection limits for parameter determined in this study.

Parameter	EPA Method	Detection Limit
Arsenic	206.2	0.001 mg/L
Cadmium	213.2	0.001 mg/L
Conductivity	120.1	0.1 μ S/cm
Copper	220.2	0.001 mg/L
Dissolved Oxygen	360.1	0.1 mg/L
Hardness	130.2	1 mg/L
Lead	239.2	0.001 mg/L
pH	150.1	0.01 unit
Total Suspended Solids	160.2	0.1 mg/L
Turbidity	180.1	0.1 NTU
Zinc	AES 0029	0.005 mg/L

Sampling plan

Samples were collected every six hours over a four day period. These samples were used in the calculation of the four-day means. However during a 24 hour period, samples were collected every three hours and the results were used in the **24-hour** means. The downstream site was sampled first, so that any disturbance which occurred at the upstream site would not have any influence on the data collected at the downstream site.

Water Quality Standards

The water quality standards for the five metals sampled in this study are quite different. Table 2 gives the sample preparation method and the water quality criteria (formula given if hardness dependent). These standards are based on the Alaska Water Quality Standards Workbook (ADEC, 1991).

Table 2. Water quality standards for the five trace metals.

Metal	Sample Preparation	Criteria	Mean
Arsenic	Total	50 µg/L	Instant
Cadmium	Dissolved	$e^{[(0.7853) \ln(\text{hardness}) - 3.490]} \mu\text{g/L}$	4-day
Copper	Dissolved	$e^{[(0.8545) \ln(\text{hardness}) - 1.465]} \mu\text{g/L}$	4-day
Lead	Dissolved	$e^{[(1.266) \ln(\text{hardness}) - 4.661]} \mu\text{g/L}$	4-day
Zinc	Total Recoverable	47 µg/L	24-hour

RESULTS AND DISCUSSION

Physical and Field Parameters

Table 3 presents the mean values of the physical and field data collected at both Fairbanks and Porcupine creeks. These mean values were calculated using the 16 values which were collected at six-hour intervals (the additional samples collected for the **24-hour** mean calculations were not used). All the physical and field data collected from both creeks are located in Appendix A.

The mean values at the Fairbanks Creek sites changed from the above-mining to the below-mining site. These changes are a result of two factors. First, the entire flow of Fairbanks Creek flows through the settling pond system, causing the residence time to increase. The increase in residence time allows the water to warm and be in contact with the atmosphere. These two factors caused the mean **pH** to rise 1 **pH** unit. The percentage of dissolved oxygen saturation also increased due to the atmospheric contact and the turbulent outflow of the last settling pond.

The second factor was the increase in flow between the two sites. Although there was no additional surface water input, numerous groundwater seeps increased the mean flow from 0.21 cfs to 0.94 cfs. The ground water is more mineralized than the surface water above mining as indicated by the hardness and specific conductivity (both increased by a factor of three at the below mining site). These two parameters are proportional to the amount of dissolved constituents.

Table 3. Mean values for the physical and field parameters for both Fairbanks and Porcupine creeks.

Parameter	Fairbanks Cr. above mining	Fairbanks Cr. below mining	Porcupine Cr. above mining	Porcupine Cr. below mining
Air Temperature (°C)	15.0	17.5	8.6	9.3
Water Temperature (°C)	5.0	13.4	6.2	6.3
Dissolved Oxygen (mg/L)	9.5	9.2	10.6	10.8
D.O. percent saturated	17.9	92.0	89.7	91.4
pH	6.71	7.74	7.00	7.01
Specific Cond. (µS/cm)	65.9	183	115	115
Hardness (mg/L)	30	98	56	55
Turbidity (NTU)	1.7	44	0.76	51
Suspended sediment (mg/L)	0.42	10.7	0.96	20.3
Discharge (cfs)	0.21	0.94	19.1	27.9

The mean turbidity in Fairbanks Creek increased from 1.7 to 44 NTU, while the suspended sediment increased **from** 0.42 to 10.7 **mg/L**. The turbidity at the respective sites remained nearly constant, The suspended sediment concentration did vary some.

The mean values at the Porcupine Creek sites were the same, with the only exception being the increase in sediment at the below-mining site (there was also a slight increase in the percent saturation of dissolved oxygen). These results are expected since the entire flow of Porcupine Creek is diverted around the mine site. The only water which is affected by the mining operation is the groundwater infiltration. The groundwater infiltration probably is seepage from Porcupine Creek mixed with ground water from the basin. Additional surface water flows into Porcupine Creek below the mine but above the below-mining site.

Table 4 shows the mean values of the field and physical parameters for the tributaries to Porcupine Creek. The mean values of the largest of these tributaries, Yankee Creek, were very similar to Porcupine Creek. Although the unnamed creek had different mean values, it contributed relatively little flow to Porcupine Creek.

Table 4. Mean values for the physical and field parameters for both tributaries to Porcupine Creek.

Parameter	Yankee Creek	unnamed creek
Air Temperature (°C)	10.2	10.6
Water Temperature (°C)	5.3	2.8
Dissolved Oxygen (mg/L)	11.6	12.2
D.O. percent saturated	96.5	94.6
pH	7.22	7.29
Specific Cond. (µS/cm)	117	35
Hardness (mg/L)	56	27
Turbidity (NTU)	0.62	1.1
Suspended sediment (mg/L)	1.77	0.35
Discharge (cfs)	3.9	1.3

Trace Metals

Environmental scientists frequently encounter water quality data that contain sample concentrations reported as “less than detection.” These “less than” values (statisticians call these “censored data”) complicate the analysis of the data. Compliance with wastewater discharge regulations is usually determined by

comparing the mean of concentrations observed over some time with a legal standard. However the mean cannot be directly calculated when censored data are present.

Environmental quality data usually are positively skewed (Helsel and Cohn, 1988). Most data sets are characterized by mostly low values with a few high “outliers.” This results in the mean and standard deviation being strongly affected by those **few** high values. For positively skewed data, the mean may be exceeded by less than half the data, sometimes even by 25 percent or less (Helsel, 1990). When the strong influence of one large value distorts the summaries of data characteristics, the mean and standard deviation usually are not appropriate measures (Helsel, 1990). The median is not as strongly **affected** by a few outliers as the mean is. It is a more stable estimator of the typical value of skewed data and is similar to the mean for symmetric data. When censored data are present, the median can be an important summary statistic. If less than 50 percent of the data are censored, then the median can be calculated without any effect from the censored data. However, since most water quality regulations are written using the mean as the comparative statistic, it is necessary to calculate the mean including the censored data.

When all the data are available, whether or not the data are below the detection limit, it is possible to calculate the mean directly using **all** the data (Gilbert, 1987). However most labs do not report the “less than” values, but report “below detection.” There are three general methods for estimating summary statistics of data which include censored values. The most widely used method (although there is no theoretical basis) is the simple substitution method. This method substitutes a single value for the censored value. The substitution of zero produces estimates which are biased low, while substitution of the detection limit produces estimates which are biased high (Helsel, 1990). The results of substituting one-half the detection limit are also poor when compared to other methods (Gleit, 1985). Since large differences may occur in the resulting estimates, and the choice for the value of substitution is essentially arbitrary, **estimates resulting from simple substitution are not defensible (Helsel, 1990).**

The second method is the distributional method. The values above and below the detection limit are assumed to follow a distribution (most often **lognormal**). Given the distribution, estimates of the summary statistics are computed (using maximum likelihood estimation or probability plotting procedures) that best match the values reported and the percentage of the data below the detection limit (Helsel, 1990). This

method has some problems with estimating the moment statistics (mean and standard deviation) (Gilliom and Helsel, 1986). Failure of the assumed distribution to “fit” the high outlier values can lead to poor estimations of the mean and standard deviation. As with any transformation, there is a bias inherent in computing estimates of the mean and standard deviation when transforming back to the original units (Cohn, 1988).

The third method is the robust method. This method fits a distribution to the data above the detection limit (by either maximum likelihood estimation or probability plot procedures), but this distribution is used only to identify a collection of values below the detection limit. These values are not estimates for specific samples, but are used collectively to estimate the summary statistics (Helsel, 1990). There are two main advantages of this method. First, the estimates of the moment statistics are not sensitive to the distribution fit at the high outlier values since the actual data above the detection limit are used. Second, the values below the detection limit can be retransformed directly and summary statistics computed, avoiding transformation bias (Helsel, 1990).

Since the Division of Water - Water Quality Laboratory performed the trace metal analyses, all the values were available (including the values which were actually below the detection limit). Using all these data, means and medians for the trace metals at the four sites were calculated (Table 5.). The complete listing of trace metal data is found in Appendix B (the data have been censored at the detection limits specified in Table 1). The four-day mean was reported for arsenic, cadmium, copper and lead. These means are based on 16 samples at six-hour intervals. Although the arsenic standard is based on an instantaneous concentration and not a mean, it was included for comparison to the maximum value. The **24-hour** mean for zinc is based on eight samples at three-hour intervals. The calculated value is reported in parentheses for analytes with a mean or median less than the detection limit. The water quality standards for cadmium, copper and lead were calculated using the mean hardness from the 16 samples and the appropriate formula (specified in Table 2).

The water quality standard of 50 $\mu\text{g/L}$ for arsenic was exceeded at Fairbanks Creek below mining. Every sample collected exceeded the standard, with a maximum concentration of 112 $\mu\text{g/L}$. The mean arsenic concentration was 89 $\mu\text{g/L}$. The mean concentration above mining was 30 $\mu\text{g/L}$, with a maximum concentration of 36 $\mu\text{g/L}$. There are many seeps between the two sites, with the flow increasing by a factor of greater than four. Since this area is highly mineralized, and other creeks in the area are known to have high

Table 5. Mean and median values of the five trace metals for the four sampling sites. The water quality standards which are based on hardness are calculated using the mean hardness from the 1-day period. For means and medians which are below the detection limit, the calculated value is given in parentheses. Number of censored data are the number of values below the detection limit which were used in the calculation of the mean. The maximum is the highest value reported during the time period for the standard.

Parameter	Water Quality Standard	n	mean (µg/L)	median (µg/L)	number of censored data	maximum (µg/L)
Fairbanks Creek above Mining						
Total Arsenic	50 µg/L	16	30	32	0	36
Dissolved Cadmium	0.44 µg/L	16	<DL (0.05)	<DL (0.04)	16	<DL
Dissolved Copper	4.2 µg/L	16	<DL (0.55)	<DL (0.58)	14	2.7
Dissolved Lead	0.70 µg/L	16	<DL (0.51)	<DL (0.49)	15	1.0
Total Rec. Zinc	47 µg/L	8	27	24	0	46
Fairbanks Creek below Mining						
Total Arsenic	50 µg/L	16	89	87	0	112
Dissolved Cadmium	1.1 µg/L	16	<DL (0.02)	<DL (0.02)	16	<DL
Dissolved Copper	12 µg/L	16	<DL (0.79)	<DL (0.46)	14	6.2
Dissolved Lead	3.1 µg/L	16	1.0	<DL (0.72)	9	2.6
Total Rec. Zinc	47 µg/L	8	21	21	0	28
Porcupine Creek above Mining						
Total Arsenic	50 µg/L	16	1.8	<DL (0.22)	12	15
Dissolved Cadmium	0.72 µg/L	16	<DL (0.12)	<DL (0.13)	16	<DL
Dissolved Copper	7.2 µg/L	16	4.1	3.4	0	7.5
Dissolved Lead	1.5 µg/L	16	<DL (0.30)	<DL (0.21)	15	1.6
Total Rec. Zinc	47 µg/L	8	28	25	1	92
Porcupine Creek below Mining						
Total Arsenic	50 µg/L	16	9.1	9.7	1	20
Dissolved Cadmium	0.71 µg/L	16	<DL (0.07)	<DL (0.07)	16	<DL
Dissolved Copper	7.1 µg/L	16	4.8	4.3	0	12
Dissolved Lead	1.5 µg/L	16	1.5	1.8	6	3.0
Total Rec. Zinc	47 µg/L	8	29	26	0	54

arsenic concentrations, it is suspected that the high arsenic concentration was **from** the groundwater seeps. Additional samples were collected above and below mining on November 5, 1991. Since mining had ceased six weeks earlier and the creek was ice-covered, the sample should measure the quality of the ground water component of the flow. The mean concentration above and below mining for these samples were 29 and 75 $\mu\text{g/L}$, respectively. These values are **very** similar to the mean concentrations from the summer samples. This suggests that the ground water contributes much of the arsenic to Fairbanks Creek. The other metals were within the water quality standards.

All the sampled metals at both Porcupine Creek sites were within the water quality standards. The metal with a mean closest to the standard was dissolved lead, which was at the limit of 1.5 $\mu\text{g/L}$. The other metals were well below the limits.

Table 6 shows the change in concentration of the metals from above mining to below mining. Total arsenic increased the most (described previously), with some of the other metals increasing only 1 $\mu\text{g/L}$. Cadmium showed no trend since the concentrations were below detection. Zinc actually decreased in concentration at Fairbanks Creek, but the total load increased. This indicates that the groundwater seeps have a relatively lower zinc concentration.

Table 6. Change in metal concentration from above to below mining. All values in $\mu\text{g/L}$.

Site		Total Arsenic	Dissolved Cadmium	Dissolved Copper	Dissolved Lead	Total Recoverable Zinc
Fairbanks	Creek	+59	----	----	~0.5	- 6
Porcupine	Creek	+7.3	----	+0.7	+1.2	+1.0

FURTHER RESEARCH

The difficulty of collecting samples for the **24-hour** and four-day means quickly became evident during this study. Little information existed on designing a sampling plan for these methods. There are three topics associated with this project which need further research. The topics are as follows:

1. A statistically defensible sampling design must be investigated. The sampling design for this project was generated mainly out of practicality and convenience. Four samples collected per day over a four day period “seemed” like a practical and cost effective schedule for a preliminary study. There was no information available on the variance of the metals in the creeks being sampled.

It is possible to estimate the probability of error associated with the means in this study if some assumptions are made. Since σ^2 (population variance) is not known, the coefficient of variation ($\eta = \sigma/\mu$) will be used (the sample mean and variance will be substituted for the population mean and variance). The coefficient of variation is usually less variable from one site or time period to another than σ^2 is (Gilbert, 1987). The relative error (d_r) is defined as the difference between the sample mean and the population mean divided by the population mean. This indicates how close the sampling estimates the population mean. The formula and method for this calculation is found in Gilbert (1987). Based on the sixteen samples collected, there is a ten percent chance that the relative error will exceed six percent for the total arsenic mean at Fairbanks Creek above mining. However, there is a ten percent chance that the relative error will exceed 35 percent for the total recoverable zinc value at Porcupine Creek above mining. It is also possible to calculate the number a samples which would need to be collected such that there would only be a ten percent chance that the relative difference would exceed ten percent, Based on the data collected in this study, the number of samples collected for total arsenic at Fairbanks Creek above mining is six, and 170 samples collected for total recoverable zinc at Porcupine Creek above mining. The goal of the sampling is to estimate the population mean with as few samples as possible while maintaining the desired level of accuracy and precision.

2. Once the sampling schedule has been statistically designed, investigate alternative sampling techniques; such as automated samplers and composite samples. The Alaska Water Quality Standards

Workbook (ADEC, 1991) recommends the use of automated water samplers to collect the samples for the **four-** day mean. This may not be a valid technique. The possibility for cross-contamination of the samples exists for the trace metals since there is no way to acid wash and rinse the sampling tube between samples. Since the samples would have to be acidified for preservation at the time of collection, only samples for **total** and **total-** recoverable analyses (arsenic and zinc) could be collected. It would not be possible to collect samples for dissolved-metal analysis. Another problem with automated samples is they essentially take a “grab” sample. The water sample is taken at only one place in the stream. The proper method of sampling is to take a composited sample using a depth-integrating sampler and churn splitter (USDI, 1977). The use of grab samples could bias the results in a stream which is not thoroughly mixed. Further literature and technical review is necessary before this technique can be recommended.

To help control the cost of laboratory sample analysis, samples could be composited in the field, reducing the number of samples collected. Instead of putting each sample in a separate bottle, samples could be composited into one bottle for each day. This would result in only four one-day samples to be analyzed. This would allow flexibility in the number of samples collected each day without increasing the cost of analysis. Only minor statistical changes would be necessary in the sampling design.

3. Once the sampling design and sampling methods have been determined, sample additional mines to determine if the metals exceed water quality standards. This is the ultimate goal of the project. Although the metals which are not presently monitored (Cd, Cu, Pb, and Zn) did not exceed the water quality standards in this study, the samples only represent two mines out of many in the interior region.

CONCLUSIONS

1. Even though both mines were not in compliance with the turbidity criterion, neither mine exceeded the water quality standards for cadmium, copper, lead or zinc. Arsenic exceeded the water quality standard below mining on Fairbanks Creek, however the high concentration is apparently due to a high concentration of arsenic in the ground water.
2. Arsenic was the only metal to show a significant increase below mining. The other metals increased by less than 1 $\mu\text{g/L}$ (if at all).
3. The Alaska Department of Environmental Conservation needs to establish a defensible method for calculating a mean for a data set with censored data. Simple substitution is not an acceptable method.
4. Further investigation is necessary on the statistical design, techniques and methods for collecting samples for the four-day mean. For example, this study showed that six samples for total arsenic at Fairbanks Creek above mining were adequate, but 170 samples for total recoverable zinc would be required at Porcupine Creek above mining to achieve the same degree of precision. This investigation should also include the use of automated samplers.

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Appendix A

Physical and field parameters.

Fairbanks Creek above mining

Date	Time	Air Temp (°C)	Water Temp (°C)	Dissolved Oxygen (mg/L)	D.O. Percent Saturated	pH	Specific Conductance (uS/cm)	Hardness as CaCO ₃ (mg/L)	Turbidity (NTU)	Suspended Solids (mg/L)	Discharge (cfs)
17-Jun-91	1700	17.5	5.9	9.1	76.7	6.72	71.0	27	1.5	0.41	0.21
17-Jun-91	2300	10.0	4.3	10.1	81.3	6.90	62.0	32	2.7	0.66	0.22
18-Jun-91	500	0.4	2.8	10.3	79.7	6.94	64.5	29	2.4	0.23	0.22
18-Jun-91	1100	18.3	4.4	9.3	75.4	6.85	64.0	29	1.8	0.21	0.21
18-Jun-91	1700	21.8	6.2	9.0	76.5	6.54	66.9	31	1.7	0.24	0.20
18-Jun-91	2000	17.0	5.4	9.9	82.1	6.66	67.4	30	2.5	4.11	0.20
18-Jun-91	2300	7.1	4.5	9.3	75.6	6.65	65.0	28	1.8	0.22	0.21
19-Jun-91	200	4.2	3.6	10.5	82.9	6.73	65.1	27	2.0	0.00	0.23
19-Jun-91	500	4.3	3.1	10.8	84.8	6.90	65.0	31	1.8	0.24	0.22
19-Jun-91	800	13.3	3.3	10.3	80.7	6.99	66.0	28	1.6	0.22	0.22
19-Jun-91	1100	23.0	4.9	9.5	77.9	6.75	65.9	32	1.3	0.22	0.20
19-Jun-91	1400	22.2	6.4	8.9	76.1	6.65	66.4	25	1.2	0.55	0.21
19-Jun-91	1700	21.4	6.8	9.3	80.1	6.67	66.4	30	1.7	0.40	0.21
19-Jun-91	2300	9.4	5.2	9.6	79.3	6.68	64.0	29	1.4	0.49	0.22
20-Jun-91	500	6.6	3.6	10.3	81.4	6.72	66.4	29	1.4	0.57	0.22
20-Jun-91	1100	24.5	5.4	9.1	75.8	6.68	66.9	29	1.4	0.23	0.21
20-Jun-91	1700	27.3	7.0	9.0	78.0	6.66	67.7	30	1.4	0.25	0.20
20-Jun-91	2300	13.2	5.4	8.6	71.0	6.63	66.6	28	1.3	0.70	0.21
21-Jun-91	500	9.6	4.0	9.5	76.1	6.53	66.6	30	1.9	0.44	0.21
21-Jun-91	1100	26.0	5.8	9.1	76.5	6.57	66.0	29	1.5	1.17	0.21

Appendix A (cont)

Physical and field parameters.

Fairbanks Creek below mining

Date	Time	Air Temp (°C)	Water Temp (°C)	Dissolved Oxygen (mg/L)	D.O. Percent Saturated	pH	Specific Conductance (µS/cm)	Hardness as CaCO ₃ (mg/L)	Turbidity (NTU)	Suspended Solids (mg/L)	Discharge (cfs)
17-Jun-91	1600	18.5	14.6	8.8	90.9	7.62	186	96	45	12.5	0.87
17-Jun-91	2200	16.2	11.5	9.7	93.1	7.43	180	101	46	4.10	0.80
18-Jun-91	400	4.0	9.4	10.3	94.0	7.43	175	99	45	11.6	0.91
18-Jun-91	1000	17.3	12.2	9.1	89.0	7.42	176	100	42	13.9	0.94
18-Jun-91	1600	19.7	14.3	9.5	97.1	7.62	186	96	44	12.4	0.98
18-Jun-91	1900	19.3	13.8	9.0	91.3	7.88	185	96	46	18.7	1.02
18-Jun-91	2200	15.5	12.4	9.5	93.2	7.65	177	96	49	10.2	1.01
19-Jun-91	100	7.2	11.1	9.9	94.3	7.74	180	96	49	14.7	1.03
19-Jun-91	400	6.7	10.3	10.0	93.5	7.78	177	95	46	10.2	1.06
19-Jun-91	700	11.6	10.6	9.9	93.0	7.80	181	96	46	18.5	1.11
19-Jun-91	1000	20.2	13.0	9.3	92.5	7.63	180	100	47	8.98	1.10
19-Jun-91	1300	20.4	15.5	8.8	92.6	7.77	182	97	46	17.3	1.08
19-Jun-91	1600	23.3	17.2	8.6	92.9	8.02	182	93	46	19.7	1.04
19-Jun-91	2200	17.0	14.1	8.7	88.9	7.82	182	95	44	11.7	1.00
20-Jun-91	400	10.2	11.3	9.6	91.8	7.70	184	97	42	9.77	0.93
20-Jun-91	1000	25.5	14.3	9.0	92.2	7.98	186	98	42	10.5	0.95
20-Jun-91	1600	28.7	17.8	8.4	91.9	7.93	189	100	42	11.0	0.90
20-Jun-91	2200	19.6	15.1	8.6	88.9	7.89	187	96	46	8.41	0.87
21-Jun-91	400	12.4	12.1	9.4	91.6	7.83	187	98	37	8.57	0.85
21-Jun-91	1000	25.0	15.3	8.7	91.3	8.08	188	100	36	7.27	0.81

Appendix A (cont)

Physical and field parameters.

Porcupine Creek above mining

Date	Time	Air Temp (°C)	Water Temp (°C)	Dissolved Oxygen (mg/L)	D.O. Percent Saturated	pH	Specific Conductance (µS/cm)	Hardness as CaCO ₃ (mg/L)	Turbidity (NTU)	Suspended Solids (mg/L)	Discharge (cfs)
05-Aug-9	1 1700	14.2	7.4	10.1	88.2	6.84	117	55	0.90	2.73	28.6
05-Aug-9	1 2000	12.1	7.0	10.2	88.2	6.87	117	53	1.1	2.22	28.1
05-Aug-91	2300	10.7	6.3	10.2	86.7	6.91	118	54	0.60	1.18	27.3
06-Aug-9	1 200	9.7	6.0	10.2	86.0	7.05	117	54	1.0	0.79	26.5
06-Aug-9	1 500	6.9	5.7	10.4	87.1	6.95	115	56	0.65	1.14	25.6
06-Aug-9	1 800	7.3	5.9	10.9	91.7	7.01	114	54	1.2	2.20	24.8
06-Aug-9	1 1100	6.3	5.9	10.4	87.5	7.02	114	54	1.1	2.65	24.0
06-Aug-9	1 1400	6.9	5.9	10.9	91.7	7.14	118	55	1.1	0.44	23.2
06-Aug-9	1 1700	10.3	6.9	10.6	91.4	7.16	113	58	0.75	0.44	22.5
06-Aug-91	2300	7.8	5.7	10.3	86.2	7.22	113	58	1.0	0.23	21.3
07-Aug-9	1 500	6.7	5.1	11.1	91.5	6.98	113	56	0.90	0.21	20.0
07-Aug-91	1100	8.0	5.9	11.4	95.9	7.00	113	53	0.65	0.23	19.0
07-Aug-9	1 1700	8.3	6.6	11.2	100	7.08	113	53	0.60	0.25	18.0
07-Aug-91	23 00	8.3	5.8	10.1	84.8	6.86	114	56	0.70	1.49	17.0
08-Aug-91	5 0 0	6.7	5.6	10.8	90.2	6.92	113	56	0.70	0.40	16.0
08-Aug-91	1100	8.6	6.1	10.8	91.3	6.93	116	57	0.65	1.04	15.0
08-Aug-91	1700	10.7	7.3	10.3	89.7	7.14	119	53	0.70	0.44	14.0
08-Aug-9	1 2300	7.2	6.1	10.4	87.9	6.90	115	57	0.70	0.20	13.1
09-Aug-9	1 500	4.7	5.5	10.3	85.8	6.96	113	56	0.80	1.80	12.2
09-Aug-9	1 1100	11.9	6.7	10.6	91.0	7.05	116	57	0.70	0.86	11.4

Appendix A (cont)

Physical and field parameters.

Porcupine Creek below mining

Date	Time	Air Temp (°C)	Water Temp (°C)	Dissolved Oxygen (mg/L)	D.O. Percent Saturated	pH	Specific Conductance (µS/cm)	Hardness as CaCO ₃ (mg/L)	Turbidity (NTU)	Suspended Solids (mg/L)	Discharge (cfs)
05-Aug-9	1 1600	14.4	8.1	9.8	87.0	6.92	115	55	21	11.8	42.3
05-Aug-9	1 1900	14.0	7.5	10.0	87.5	6.91	113	53	23	10.9	41.2
05-Aug-9	1 2200	11.2	6.4	10.0	85.2	6.77	116	53	27	12.1	39.5
06-Aug-9	1 100	10.0	6.0	10.6	89.4	6.91	118	54	32	16.2	38.0
06-Aug-9	1 400	6.1	5.8	10.6	89.0	6.99	116	59	45	24.0	36.7
06-Aug-9	1 700	7.5	6.0	10.5	88.6	7.00	116	55	55	27.2	35.4
06-Aug-9	1 1000	7.4	6.1	10.6	89.6	6.98	114	58	60	31.7	34.0
06-Aug-9	1 1300	8.0	6.1	10.9	92.2	7.11	114	56	75	30.8	32.8
06-Aug-9	1 1600	9.8	7.0	10.2	88.2	7.11	112	55	70	29.0	31.8
06-Aug-9	1 2200	7.8	5.7	10.6	88.7	7.18	114	53	75	27.8	30.0
07-Aug-9	1 400	6.9	5.1	10.7	88.2	7.07	113	56	75	29.1	28.5
07-Aug-9	1 1000	8.6	6.2	10.8	91.6	6.95	114	56	70	27.9	27.3
07-Aug-9	1 1600	10.9	6.9	11.3	97.5	7.13	109	51	55	24.6	26.0
07-Aug-9	1 2200	8.5	5.9	10.8	90.9	7.10	116	53	55	19.9	24.7
08-Aug-9	1 400	8.0	5.4	11.4	94.7	6.91	117	57	50	15.1	23.5
08-Aug-9	1 1000	9.6	5.8	11.0	92.3	6.89	117	59	40	16.5	22.4
08-Aug-9	1 1600	14.8	8.1	10.9	96.8	7.09	119	57	40	12.5	21.2
08-Aug-9	1 2200	8.1	6.2	11.1	94.1	7.03	117	51	39	14.6	20.2
09-Aug-9	1 400	5.9	5.4	11.4	94.7	6.95	114	53	50	15.4	19.3
09-Aug-9	1 1000	10.7	6.8	10.9	93.8	7.01	114	54	45	12.9	18.6

Appendix A (cont)

Physical and field parameters.

Tributaries to Porcupine Creek

Date	Time	Air Temp (°C)	Water Temp (°C)	Dissolved Oxygen (mg/L)	D.O. Percent Saturated	pH	Specific Conductance (µS/cm)	Hardness as CaCO ₃ (mg/L)	Turbidity (NTU)	Suspended Solids (mg/L)	Discharge (cfs)
Yankee Creek											
06-Aug-91	1500	8.4	5.2	11.6	95.9	7.18	119	55	0.80	2.44	4.5
07-Aug-91	1345	11.5	5.9	11.9	100	7.19	116	57	0.60	2.45	3.8
09-Aug-91	1130	10.6	4.9	11.4	93.5	7.29	116	55	0.45	0.41	3.4
unnamed Creek											
06-Aug-91	1530	9.6	2.7	12.2	94.5	7.25	34	27	1.6	0.63	1.5
07-Aug-91	1415	11.4	3.1	11.6	90.8	7.28	35	26	1.0	0.20	1.3
09-Aug-91	1100	10.8	2.5	12.8	98.6	7.33	36	27	0.60	0.22	1.1

Appendix B

Dissolved and total trace metals (all values in $\mu\text{g/L}$).

Fairbanks Creek above mining

Date	Time	Dissolved Arsenic	Dissolved Cadmium	Dissolved Copper	Dissolved Lead	Dissolved Zinc	Total Arsenic	Total Cadmium	Total Copper	Total Lead	Total Recoverable Zinc
17-Jun-91	1700	14	<DL	<DL	<DL	17	27	<DL	1.0	5.8	21
17-Jun-91	2300	19	<DL	<DL	<DL	10	36	<DL	<DL	<DL	27
18-Jun-91	500	9.0	<DL	<DL	<DL	23	33	<DL	4.3	<DL	28
1%Jun-91	1100	22	<DL	1.6	<DL	28	25	<DL	15	5.8	28
18-Jun-91	1700	29	<DL	<DL	<DL	23	36	<DL	<DL	<DL	39
1%Jun-91	2000	36	<DL	2.7	<DL	23	64	<DL	6.6	6.1	23
1%Jun-91	2300	12	<DL	<DL	<DL	19	33	<DL	<DL	6.5	19
19-Jun-91	200	25	<DL	<DL	<DL	15	39	<DL	<DL	<DL	21
19-Jun-91	500	29	<DL	<DL	<DL	12	33	<DL	<DL	5.6	23
19-Jun-91	800	12	<DL	<DL	<DL	32	31	<DL	1.2	6.3	46
19-Jun-91	1100	25	<DL	<DL	1.0	9.2	26	<DL	3.3	5.7	24
19-Jun-91	1400	19	<DL	<DL	<DL	20	34	<DL	2.2	<DL	22
19-Jun-91	1700	24	<DL	<DL	<DL	22	27	<DL	5.3	<DL	28
19-Jun-91	2300	34	<DL	<DL	<DL	7.8	34	<DL	4.2	5.6	23
20-Jun-91	500	20	<DL	<DL	<DL	6.6	22	<DL	<DL	<DL	24
20-Jun-91	1100	17	<DL	<DL	<DL	7.7	33	<DL	6.8	<DL	16
20-Jun-91	1700	19	<DL	<DL	<DL	7.5	32	<DL	2.8	5.1	17
20-Jun-91	2300	26	<DL	<DL	<DL	9.9	30	<DL	<DL	6.0	65
21-Jun-91	500	14	<DL	<DL	<DL	14	29	<DL	3.9	<DL	20
21-Jun-91	1100	14	<DL	<DL	<DL	17	31	<DL	2.6	5.0	31

Appendix B (cont)

Dissolved and total trace metals (all values in $\mu\text{g/L}$).

Fairbanks Creek below mining

Date	Time	Dissolved Arsenic	Dissolved Cadmium	Dissolved Copper	Dissolved Lead	Dissolved Zinc	Total Arsenic	Total Cadmium	Total Copper	Total Lead	Total Recoverable Zinc
17-Jun-91	1600	65	<DL	<DL	<DL	8.4	87	<DL	11	<DL	10
17-Jun-91	2200	84	<DL	<DL	<DL	<DL	96	<DL	10	<DL	20
18-Jun-91	400	77	<DL	<DL	<DL	9.6	85	<DL	6.9	<DL	20
18-Jun-91	1000	68	<DL	<DL	2.3	24	85	<DL	18	5.5	32
18-Jun-91	1600	84	<DL	<DL	1.1	7.8	91	<DL	7.5	5.6	18
18-Jun-91	1900	60	<DL	4.6	2.1	11	65	<DL	12	5.7	20
18-Jun-91	2200	61	<DL	6.2	<DL	8.1	76	<DL	9.4	<DL	22
19-Jun-91	100	75	<DL	<DL	<DL	12	95	<DL	8.7	5.5	18
19-Jun-91	400	65	<DL	<DL	<DL	5.8	83	<DL	13	<DL	21
19-Jun-91	700	47	<DL	4.0	<DL	21	66	<DL	8.4	<DL	22
19-Jun-91	1000	83	<DL	1.0	1.2	20	101	<DL	9.3	5.7	28
19-Jun-91	1300	49	<DL	<DL	2.1	5.9	65	<DL	13	6.3	15
19-Jun-91	1600	56	<DL	<DL	1.2	9.7	86	<DL	8.2	6.4	25
19-Jun-91	2200	51	<DL	<DL	2.6	<DL	62	<DL	20	6.0	33
20-Jun-91	400	65	<DL	<DL	<DL	8.2	112	<DL	16	<DL	14
20-Jun-91	1000	56	<DL	<DL	1.6	<DL	92	<DL	9.1	6.5	34
20-Jun-91	1600	74	<DL	<DL	<DL	15	91	<DL	6.9	<DL	33
20-Jun-91	2200	70	<DL	<DL	<DL	<DL	103	<DL	6.9	<DL	23
21-Jun-91	400	42	<DL	<DL	<DL	<DL	83	<DL	10	<DL	23
21-Jun-91	1000	41	<DL	<DL	2.0	14	86	<DL	8.8	5.5	21

Appendix B (cont)

Dissolved and total trace metals (all values in µg/L).

Porcupine Creek above mining

Date	Time	Dissolved Arsenic	Dissolved Cadmium	Dissolved Copper	Dissolved Lead	Dissolved Zinc	Total Arsenic	Total Cadmium	Total Copper	Total Lead	Total Recoverable Zinc
5-Aug-91	1600	<DL	<DL	7.5	<DL	<DL	<DL	<DL	10	2.6	14
5-Aug-91	1900	<DL	<DL	6.1	<DL	<DL	<DL	<DL	9.2	3.1	7.1
5-Aug-91	2200	<DL	<DL	6.4	<DL	<DL	<DL	<DL	8.3	2.7	92
6-Aug-9 1	100	<DL	<DL	4.6	1.7	<DL	<DL	<DL	13	1.8	<DL
6-Aug-9 1	400	<DL	<DL	5.0	<DL	<DL	<DL	<DL	11	2.5	54
6-Aug-9 1	700	<DL	<DL	4.5	1.8	5.6	<DL	<DL	14	2.0	8.7
6-Aug-9 1	1000	<DL	<DL	5.2	1.6	<DL	<DL	<DL	8.3	2.6	6.7
6-Aug-9 1	1300	<DL	<DL	4.0	1.8	<DL	<DL	<DL	9.9	2.7	19
6-Aug-9 1	1600	<DL	<DL	3.4	<DL	8.7	<DL	<DL	8.0	<DL	32
6-Aug-9 1	2200	<DL	<DL	3.0	<DL	<DL	<DL	<DL	6.0	<DL	5.0
7-Aug-9 1	400	<DL	<DL	2.9	<DL	<DL	<DL	<DL	5.3	<DL	44
7-Aug-9 1	1000	<DL	<DL	2.9	<DL	<DL	<DL	<DL	6.7	<DL	30
7-Aug-9 1	1600	<DL	<DL	3.2	<DL	<DL	<DL	<DL	6.9	<DL	44
7-Aug-9 1	2200	<DL	<DL	4.3	<DL	<DL	<DL	<DL	5.5	<DL	8.1
8-Aug-9 1	400	<DL	<DL	3.3	<DL	<DL	4.2	<DL	7.0	<DL	23
8-Aug-9 1	1000	<DL	<DL	3.2	<DL	11	4.3	<DL	9.0	<DL	12
8-Aug-9 1	1600	<DL	<DL	3.9	<DL	5.2	<DL	<DL	7.5	<DL	14
8-Aug-9 1	2200	<DL	<DL	2.7	<DL	<DL	<DL	<DL	8.4	<DL	39
9-Aug-91	400	<DL	<DL	3.3	<DL	<DL	1.1	<DL	6.7	<DL	11
9-Aug-91	1000	<DL	<DL	4.8	<DL	12	15	<DL	8.0	<DL	32

Appendix B (cont)

Dissolved and total trace metals (all values in $\mu\text{g/L}$).

Porcupine Creek below mining

Date	Time	Dissolved Arsenic	Dissolved Cadmium	Dissolved Copper	Dissolved Lead	Dissolved Zinc	Total Arsenic	Total Cadmium	Total Copper	Total Lead	Total Recoverable Zinc
5-Aug-91	1700	<DL	<DL	12	2.7	12	2.9	<DL	16	2.9	54
5-Aug-91	2000	<DL	<DL	6.5	2.5	18	7.5	<DL	7.4	2.5	42
5-Aug-91	2300	<DL	<DL	5.9	2.5	6.5	2.6	<DL	10	3.6	32
6-Aug-91	1 200	<DL	<DL	5.5	2.1	14	1.8	<DL	11	8.1	24
6-Aug-91	1 500	<DL	<DL	5.9	3.0	<DL	10	<DL	10	4.5	27
6-Aug-91	1 800	<DL	<DL	5.2	2.4	7.2	15	<DL	15	3.9	23
6-Aug-91	1 1100	<DL	<DL	3.9	1.8	<DL	15	<DL	13	6.6	8.9
6-Aug-91	1 1400	<DL	<DL	4.2	2.0	<DL	15	<DL	14	6.0	16
6-Aug-91	1 1700	<DL	<DL	3.3	<DL	12	11	<DL	11	5.3	31
6-Aug-91	1 2300	<DL	<DL	5.7	<DL	10	12	<DL	12	9.9	21
7-Aug-91	1 500	<DL	<DL	3.3	<DL	16	12	<DL	12	6.0	36
7-Aug-91	1 1100	<DL	<DL	4.8	1.5	11	4.0	<DL	19	8.2	39
7-Aug-91	1 1700	<DL	<DL	3.6	<DL	11	20	<DL	16	6.9	20
7-Aug-91	1 2300	2.5	<DL	4.2	1.7	<DL	13	<DL	17	6.9	27
8-Aug-91	1 500	<DL	<DL	3.1	<DL	17	9.3	<DL	13	4.0	44
8-Aug-91	1 1100	1.0	<DL	4.0	2.2	<DL	8.1	<DL	15	5.1	18
8-Aug-91	1 1700	4.4	<DL	4.9	2.4	7.4	6.3	<DL	15	8.2	14
8-Aug-91	1 2300	3.7	<DL	4.4	2.1	9.6	7.3	<DL	12	5.5	13
9-Aug-91	1 500	4.5	<DL	4.3	2.6	<DL	12	<DL	13	5.8	23
9-Aug-91	1 1100	<DL	<DL	4.2	<DL	17	<DL	<DL	11	2.8	52

Appendix B (cont)

Dissolved and total trace metals (all values in $\mu\text{g/L}$).

Tributaries to Porcupine Creek

Date	Time	Dissolved Arsenic	Dissolved Cadmium	Dissolved Copper	Dissolved Lead	Dissolved Zinc	Total Arsenic	Total Cadmium	Total Copper	Total Lead	Total Recoverable Zinc
Yankee Creek											
6-Aug-9	1 1500	<DL	<DL	3.1	1.8	68	<DL	<DL	<DL	1.8	76
7-Aug-9	1 1345	<DL	<DL	3.0	<DL	<DL	<DL	<DL	7.5	<DL	53
9-Aug-9	1 1130	<DL	<DL	1.8	<DL	<DL	10	<DL	7.6	7.6	26
unnamed Creek											
6-Aug-9	1 1530	<DL	<DL	<DL	<DL	16	<DL	<DL	<DL	<DL	26
7-Aug-9	1 1415	<DL	<DL	2.8	<DL	<DL	<DL	<DL	7.6	<DL	25
9-Aug-91	1100	<DL	<DL	2.7	<DL	<DL	4.9	<DL	41	80	<DL